

10/525,927

15806US

Amendment to the Claims:

This listing of claims will replace all prior versions, and listings, of claims in the application:

1. (currently amended) A system for measuring, compensating and testing numerically controlled machine tool heads and/or tables, characterized in that it comprises:

at least one support base equipped with a plurality of distance sensors; and

at least one device of the gage tool type composed of an elongated cylinder, said cylinder being equipped at one of its ends with connection means for said heads and being equipped at another opposite end with a ball, said ball being placed next to said sensors so that they are able, always and in any position, to measure a distance that separates them from said ball; and

wherein the system is operatively coupled with processing means, said processing means being adapted, through a single measure obtained by said sensors about a distance that separates said sensors from said ball, to detect the XYZ coordinates of a center of a tool in a position of interest; and

wherein said processing means comprise means for performing measure processes for errors that can be modeled, means for performing measure processes for errors that cannot be modeled and means for performing dynamic checks.

2. (original) The system according to Claim 1, characterized in that said support base is of a circular shape and is equipped with three distance sensors placed on the base in positions that are mutually offset by 120°.

3. (original) The system according to Claim 1, characterized in that said connection means are of a tapered shape and said heads are adapted to receive, in one of their moving parts, said connection means for the unmovable connection thereto during the measures.

4. (canceled)

5. (canceled)

10/525,927

15806US

6. (original) The system according to Claim 1, characterized in that said heads are operatively coupled and integrated with CNC test and control means also comprising means for performing compensation processes for errors that can be modeled and means for performing compensation processes for errors that cannot be modeled.

7. (original) The system according to Claim 1, characterized in that said support base is connected to bearing means adapted to allow a rotation of said support base up to 90° with respect to its own axis, in order to reach a plurality of operating positions between two mutually perpendicular extreme axes, said bearing means being further adapted to simultaneously allow a rotation of said support base, once having reached the extreme axis position, around the axis perpendicular thereto.

8. (currently amended) The process for measuring numerically controlled machine tool heads and/or tables using a system according to Claim 1, said process comprising the steps of:

performing a plurality of automatic measures adapted to determine the parameters of a geometric model of the head, said geometric model being the mathematical model that describes the real head behavior with respect to the theoretical ~~behaviour~~ behavior, the parameters of said model being obtained through the measures and being called errors that can be modeled, said geometric model being of a complexity that can be freely defined by a user due to an integration of said system with numeric control means (CNC), to a measuring accuracy provided by the system according to Claim 1, to an absence of collisions among moving parts and the system according to Claim 1 and to a quick acquisition of error measures;

computing the detected errors that can be modeled; ~~[[and]]~~

compensating the computed errors that can be modeled through said numeric control means (CNC) for working purposes through an integrated system; and

detecting and measuring errors not described by the model being used, said errors being called errors not able to be modeled and generating a still incorrect positioning of the head.

10/525,927

15806US

9. (original) The process according to Claim 8, characterized in that the error detecting steps are realized through said support base with the sensors that provides the position of the ball of the gage tool.

10. (currently amended) The process according to Claim 9, characterized in that the measure of the positioning errors of the ball of the gage tool is carried out through the head movement using compensations related to errors that can be modeled, the numeric control means deceming to have kept the ~~centre~~ center of the ball unmoved, the difference between theoretical coordinates and real coordinates of the ball (20) being the measured errors.

11. (original) The process according to Claim 9, characterized in that the measure of the positioning errors of the ball of the gage tool is carried out by using the values provided by the sensors of the support base that are transformed into the real coordinates of the ball of the gage tool, the difference between theoretical coordinates and real coordinates of the ball being the measured errors.

12. (original) The process according to Claim 9, characterized in that the measure of the positioning errors of the ball of the gage tool is carried out by using, as an alternative, the values provided by the sensors of the support base that are used to correct the machine linear axis position in order to take back the ball to the point where the sensors provide the initial values, the ball being not moving and the linear axis performing an additional movement with respect to the one that the numeric control means (CNC) would have imposed thereto depending on currently active compensations, said correction being the measured errors.

13. (original) The process according to Claim 12, characterized in that it further comprises a calibrating step of the sensors of the support base.

14. (original) The process according to Claim 8, characterized in that it is also adapted to perform an automatic measure of the angular positioning accuracy of the rotation axes and the parallelism of the rotation axes with linear axis through computing techniques used in the field of measuring and inspecting the geometric models, said techniques referring to the reconstruction of curves and/or surfaces through a series of points.

10/525,927

15806US

15. (currently amended) The process according to Claim 14, wherein, for a head, there are planes in which the circumference described by the tool tip lies when the following movements are realized:

axis B at 90° ; axis A that performs one revolution (circle 1),

axis A at 0° ; axis B that performs one revolution (circle 2),

said planes being perpendicular and parallel to machine tool Cartesian axes;

characterized in that such process comprises the steps of:

executing the circle 1;

rebuilding with mean square methods or the like said circle 1 through a series of points describing it;

locating the non-parallelism of the plane passing through said circle 1 with respect to the plane that is orthogonal to the ideal rotation axis of axis A;

locating the relationship between position transduced by axis A measuring systems and related tool tip location point and then computing the angular positioning accuracy of axis A;

executing the circle 2;

rebuilding with means square methods or the like said circle 2 through a series of points describing it;

locating the non-parallelism of the plane passing through said circle 2 with respect to the plane that is orthogonal to the ideal rotation axis for axis B;

locating the axis A position 0 through the component of the previously described angles that lies in the plane perpendicular to the ideal rotation axis of axis A;

locating the axis B position 0 through the measured point on circle 2 that allows having the tool as vertical; and

locating the relationship between position transduced by axis B measuring systems and related tool tip positioning point and then computing the angular positioning accuracy of axis B.

10/525,927

15806US

16. (original) The process according to Claim 8, characterized in that it automatically performs the head positioning error measures in order to obtain a number of independent algebraic equations that allow solving the parameters of the geometric model of the head.

17. (original) The process according to Claim 8, characterized in that the measures are performed by selecting a number of measures independent from the search of the model parameter resolution, extending the applicability of the process to every kind of configuration of head and/or head with table, the model arriving to such complexities as to also take into account possible positioning errors of the ball of the gage tool deriving from movement errors of linear axis, namely the axis moving the head.

18. (original) The process according to Claim 8, characterized in that, if the error compensation performed by the numeric control means (CNC) has not the same degree of complexity of the measures, the system performs the translation of the parameters of its own model into the parameters of the compensation model.

19. (currently amended) The process according to Claim 8, characterized in that the step of measuring the errors that cannot be modeled comprises the sub-steps of:

establishing only an empirical link with the position of the axis of the head, for which the relationship will be univocal;

performing two measures for every head position through two gage tools with a known and different length;

being, for a generic length of a head tool, the error a linear interpolation of the pair of three measured values DX, DY and DZ, measuring the errors DX, DY and DZ of the ball of the gage tool for all affected positions, said measures being performed first with a gage tool and then with a following gage tool; and

discretizing the position combinations of the two axes from their negative end to their positive end in order to obtain the affected positions, said discretizing being performed with an empirically established step or with error frequency analysis algorithms.

10/525,927

15806US

20. (currently amended) The process for testing numerically controlled machine tool heads and/or tables using a system according to Claim 1, said process performing the check of the dynamic ~~behaviour~~ behavior of the axes controlled by the heads and/or the movements of these axes combined with the movements of the linear axis, the analysis of the response curve of the axes compared with the programmed one allowing to analyze problems like twitching and ripple, said process operating at the presence of a pass-band of at least 1 kHz of the signal sampled by the system according to Claim 1.

21. (original) The process for compensating numerically controlled machine tool heads and/or tables using a system according to Claim 1, said process being divided into a part that performs the compensation of head movements using a geometric model and a part that performs the compensation of non-geometric errors or errors that cannot be modeled.

22. (canceled)

23. (currently amended) A process using a system according to Claim 1 for measuring a position of a center of a ball connected to axes of a machine tool, using a cylinder with a ball connected to the machine tool and three distance sensors in contact with the ball, said process comprising the steps of:

defining a fixed position (1) of the ball in the inertial system XYZ ("centered ball position");

moving the machine/head to the position (1);

driving again the ball in its centered ball position;

recording a position (2) of the machine axes XYZ (X1, Y1, Z1);

moving the machine/head to position (2);

driving again the ball in its centered ball position; and

recording a position of the machine axes XYZ (X2, Y2, Z2); and

wherein the differences $X1 - X2$, $Y1 - Y2$, $Z1 - Z2$ are the errors made by the CNC system in carrying out its movements from position (1) to position (2).

24. (canceled)

10/525,927

15806US

25. (currently amended) A process using a system according to Claim 1 for determining errors indexes regarding rectilineity, scale and orthogonality for linear axes XYZ of a machine tool starting from measures performed with a single test cylinder with ball end, said process being able to measure a same error in different positions/shapes of a measuring head, said process distinguishing which are the errors that can be associated with movements of rotating head axes with respect to movements performed by linear axes, said linear axes being also moved, following the movements of the rotating axes, in order to keep a tip of a possible tool unmoving.

26. (new) A system for measuring, compensating and testing numerically controlled machine tool heads and/or tables, characterized in that it comprises:

at least one support base equipped with a plurality of distance sensors; and

at least one device of the gage tool type composed of an elongated cylinder, said cylinder being equipped at one of its ends with connection means for said heads and being equipped at another opposite end with a ball, said ball being placed next to said sensors so that they are able, always and in any position, to measure a distance that separates them from said ball; and

wherein said support base is connected to bearing means adapted to allow a rotation of said support base up to 90° with respect to its own axis, in order to reach a plurality of operating positions between two mutually perpendicular extreme axes, said bearing means being further adapted to simultaneously allow a rotation of said support base, once having reached the extreme axis position, around the axis perpendicular thereto.

27. (new) The system according to Claim 26, characterized in that said support base is of a circular shape and is equipped with three distance sensors placed on the base in positions that are mutually offset by 120°.

28. (new) The system according to Claim 26, characterized in that said connection means are of a tapered shape and said heads are adapted to receive, in one of their moving parts, said connection means for the unmovable connection thereto during the measures.

10/525,927

15806US

29. (new) The system according to Claim 26, characterized in that it is operatively coupled with processing means, said processing means being adapted, through a single measure obtained by said sensors about a distance that separates said sensors from said ball, to detect the XYZ coordinates of a center of a tool in a position of interest.

30. (new) The system according to Claim 29, characterized in that said processing means comprise means for performing measure processes for errors that can be modeled, means for performing measure processes for errors that cannot be modeled and means for performing dynamic checks.

31. (new) The system according to Claim 26, characterized in that said heads are operatively coupled and integrated with CNC test and control means also comprising means for performing compensation processes for errors that can be modeled and means for performing compensation processes for errors that cannot be modeled.

32. (new) The process for measuring numerically controlled machine tool heads and/or tables using a system according to Claim 26, said process comprising the steps of:

performing a plurality of automatic measures adapted to determine the parameters of a geometric model of the head, said geometric model being the mathematical model that describes the real head behavior with respect to the theoretical behavior, the parameters of said model being obtained through the measures and being called errors that can be modeled, said geometric model being of a complexity that can be freely defined by a user due to an integration of said system with numeric control means (CNC), to a measuring accuracy provided by the system according to Claim 26, to an absence of collisions among moving parts and the system according to Claim 1 and to a quick acquisition of error measures;

computing the detected errors that can be modeled;

compensating the computed errors that can be modeled through said numeric control means (CNC) for working purposes through an integrated system; and

detecting and measuring errors not described by the model being used, said errors being called errors not able to be modeled and generating a still incorrect positioning of the head.

10/525,927

15806US

33. (new) The process according to Claim 32, characterized in that the error detecting steps are realized through said support base with the sensors that provides the position of the ball of the gage tool.

34. (new) The process according to Claim 33, characterized in that the measure of the positioning errors of the ball of the gage tool is carried out through the head movement using compensations related to errors that can be modeled, the numeric control means deeming to have kept the center of the ball unmoved, the difference between theoretical coordinates and real coordinates of the ball being the measured errors.

35. (new) The process according to Claim 33, characterized in that the measure of the positioning errors of the ball of the gage tool is carried out by using the values provided by the sensors of the support base that are transformed into the real coordinates of the ball of the gage tool, the difference between theoretical coordinates and real coordinates of the ball being the measured errors.

36. (new) The process according to Claim 33, characterized in that the measure of the positioning errors of the ball of the gage tool is carried out by using, as an alternative, the values provided by the sensors of the support base that are used to correct the machine linear axis position in order to take back the ball to the point where the sensors provide the initial values, the ball being not moving and the linear axis performing an additional movement with respect to the one that the numeric control means (CNC) would have imposed thereto depending on currently active compensations, said correction being the measured errors.

37. (new) The process according to Claim 36, characterized in that it further comprises a calibrating step of the sensors of the support base.

38. (new) The process according to Claim 32, characterized in that it is also adapted to perform an automatic measure of the angular positioning accuracy of the rotation axes and the parallelism of the rotation axes with linear axis through computing techniques used in the field of measuring and inspecting the geometric models, said techniques referring to the reconstruction of curves and/or surfaces through a series of points.

10/525,927

15806US

39. (new) The process according to Claim 38, wherein, for a head, there are planes in which the circumference described by the tool tip lies when the following movements are realized:

axis B at 90°; axis A that performs one revolution (circle 1),

axis A at 0°; axis B that performs one revolution (circle 2),

said planes being perpendicular and parallel to machine tool Cartesian axes;

characterized in that such process comprises the steps of:

executing the circle 1;

rebuilding with mean square methods or the like said circle 1 through a series of points describing it;

locating the non-parallelism of the plane passing through said circle 1 with respect to the plane that is orthogonal to the ideal rotation axis of axis A;

locating the relationship between position transduced by axis A measuring systems and related tool tip location point and then computing the angular positioning accuracy of axis A;

executing the circle 2;

rebuilding with means square methods or the like said circle 2 through a series of points describing it;

locating the non-parallelism of the plane passing through said circle 2 with respect to the plane that is orthogonal to the ideal rotation axis for axis B;

locating the axis A position 0 through the component of the previously described angles that lies in the plane perpendicular to the ideal rotation axis of axis A;

locating the axis B position 0 through the measured point on circle 2 that allows having the tool as vertical; and

locating the relationship between position transduced by axis B measuring systems and related tool tip positioning point and then computing the angular positioning accuracy of axis B.

10/525,927

15806US

40. (new) The process according to Claim 32, characterized in that it automatically performs the head positioning error measures in order to obtain a number of independent algebraic equations that allow solving the parameters of the geometric model of the head.

41. (new) The process according to Claim 32, characterized in that the measures are performed by selecting a number of measures independent from the search of the model parameter resolution, extending the applicability of the process to every kind of configuration of head and/or head with table, the model arriving to such complexities as to also take into account possible positioning errors of the ball of the gage tool deriving from movement errors of linear axis, namely the axis moving the head.

42. (new) The process according to Claim 32, characterized in that, if the error compensation performed by the numeric control means (CNC) has not the same degree of complexity of the measures, the system performs the translation of the parameters of its own model into the parameters of the compensation model.

43. (new) The process according to Claim 32, characterized in that the step of measuring the errors that cannot be modeled comprises the sub-steps of:

establishing only an empirical link with the position of the axis of the head, for which the relationship will be univocal;

performing two measures for every head position through two gage tools with a known and different length;

being, for a generic length of a head tool, the error a linear interpolation of the pair of three measured values DX, DY and DZ, measuring the errors DX, DY and DZ of the ball of the gage tool for all affected positions, said measures being performed first with a gage tool and then with a following gage tool; and

discretizing the position combinations of the two axes from their negative end to their positive end in order to obtain the affected positions, said discretizing being performed with an empirically established step or with error frequency analysis algorithms.

10/525,927

15806US

44. (new) The process for testing numerically controlled machine tool heads and/or tables using a system according to Claim 26, said process performing the check of the dynamic behavior of the axes controlled by the heads and/or the movements of these axes combined with the movements of the linear axis, the analysis of the response curve of the axes compared with the programmed one allowing to analyze problems like twitching and ripple, said process operating at the presence of a pass-band of at least 1 kHz of the signal sampled by the system according to Claim 1.

45. (new) The process for compensating numerically controlled machine tool heads and/or tables using a system according to Claim 26, said process being divided into a part that performs the compensation of head movements using a geometric model and a part that performs the compensation of non-geometric errors or errors that cannot be modeled.

46. (new) A process using a system according to Claim 1 for measuring a position of a center of a ball connected to axes of a machine tool, using a cylinder with a ball connected to the machine tool and three distance sensors in contact with the ball, said process comprising the steps of:

defining a fixed position (1) of the ball in the inertial system XYZ ("centered ball position");

moving the machine/head to the position (1);

driving again the ball in its centered ball position;

recording a position (2) of the machine axes XYZ (X1, Y1, Z1);

moving the machine/head to position (2);

driving again the ball in its centered ball position; and

recording a position of the machine axes XYZ (X2, Y2, Z2); and

wherein the differences $X1 - X2$, $Y1 - Y2$, $Z1 - Z2$ are the errors made by the CNC system in carrying out its movements from position (1) to position (2).

47. (new) A process using a system according to Claim 1 for determining errors indexes regarding rectilineity, scale and orthogonality for linear axes XYZ of a machine tool

10/525,927

15806US

starting from measures performed with a single test cylinder with ball end, said process being able to measure a same error in different positions/shapes of a measuring head, said process distinguishing which are the errors that can be associated with movements of rotating head axes with respect to movements performed by linear axes, said linear axes being also moved, following the movements of the rotating axes, in order to keep a tip of a possible tool unmoving.